TTCI®

TRANSPORTATION TECHNOLOGY CENTER, INC.

Pueblo, Colorado USA
www.ttci.tech

ASSOCIATION OF AMERICAN RAILROADS

TTCI is a wholly owned subsidiary of the Association of American Railroads

Research Motivation

- **Rail/Track Inspection is key for assuring Safety & Structural integrity in rails**
  - **GOAL – 0 TRACK RELATED ACCIDENTS**
  - Growing demand for higher axle loads
  - Fatigue defects and RCF are ongoing issues
  - Other challenges

Example of a Rail Failure

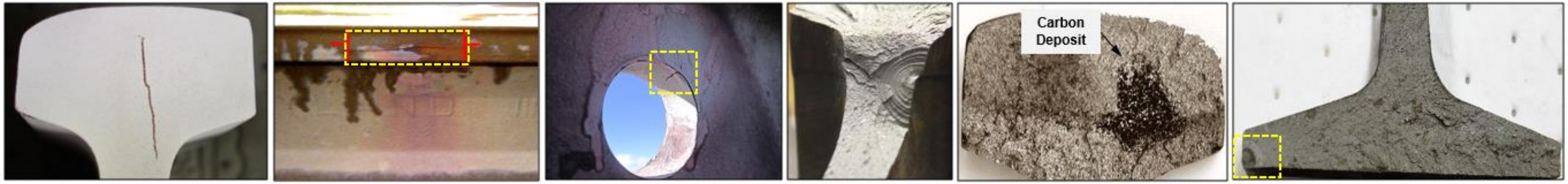
Hand-held Ultrasound Testing

Collaborative Approach

Rail Defects

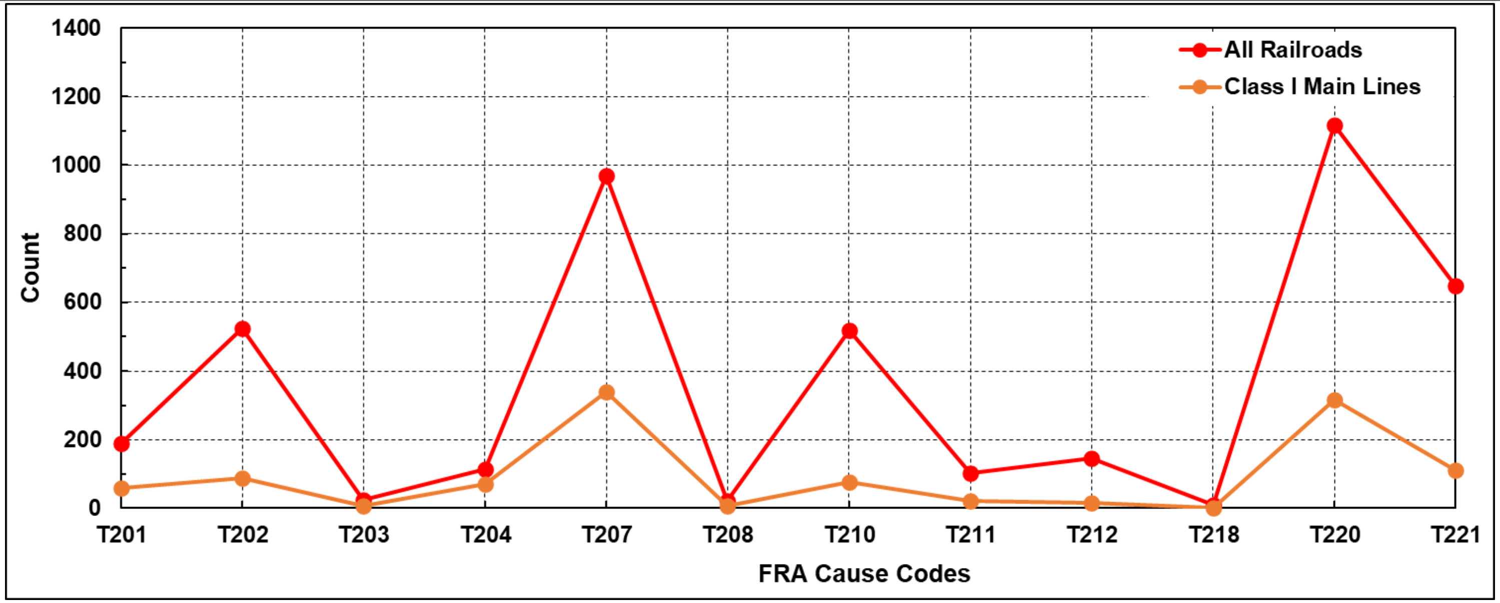
- **Rail defects develop from a number of causes. Mainly, repeated cyclic loading can initiate defects at microscopic anomalies**
  - Such defects will start and grow internally with accumulated traffic (mileage and tonnage)

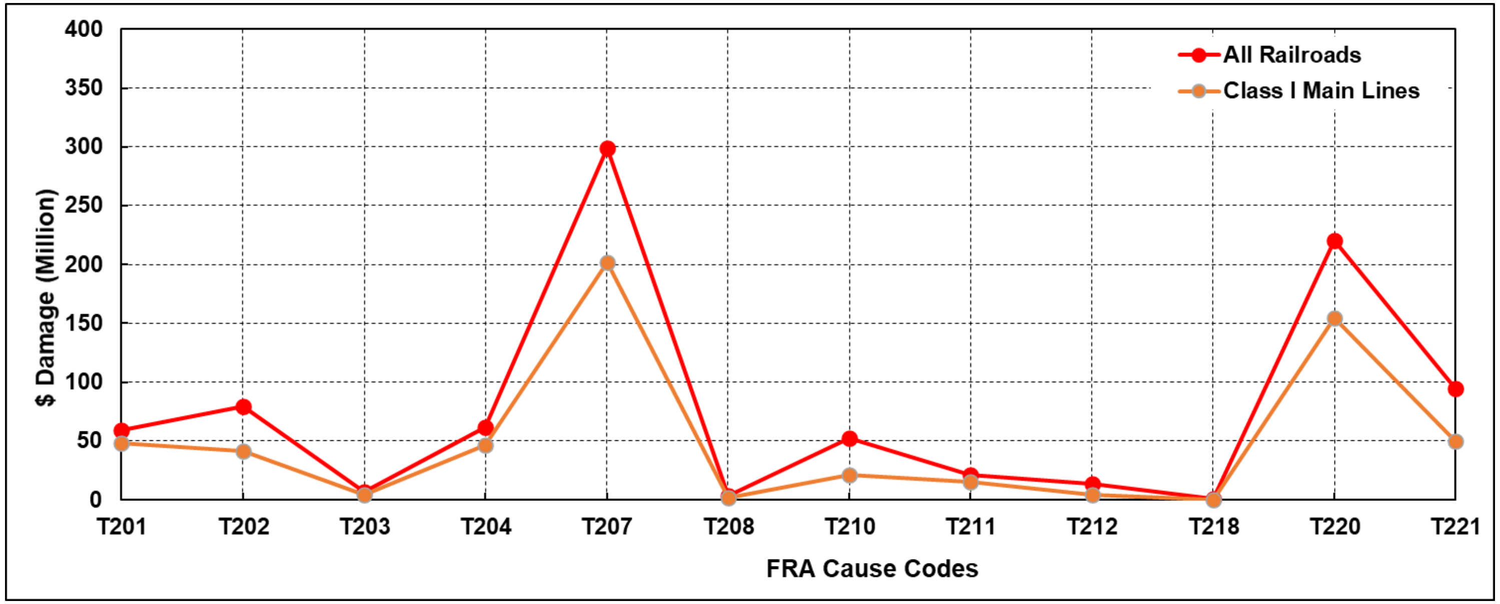
Transverse fissure (TF) | Compound Fissure (CF) | Detail Fracture (DF) | DF under Shelling | Reverse DF | Engine Burn Fracture



Vertical Split Head (VSH) | Horizontal Split Head (HSH) | Bolt Hole Crack (BHC) | Web Defect | Weld Defect | Base Defect

Broken Rail Derailment (Year 2000 – 2018)





Code	Causes (Broken Rail)
T201	Bolt hole crack or break
T202	Base
T203	Weld (plant)
T204	Weld (field)
T207	Detail fracture from shelling or head check
T208	Engine burn fracture
T210	Head and web separation (outside joint bar limits)
T211	Head and webseparation (within joint bar limits)
T212	Horizontal split head
T218	Piped rail
T220	Transverse/compound
T221	Vertical split head

Rail Flaw Inspection

- **Ultrasonic Testing (UT) non-destructive evaluation (NDE) methods for rail flaw detection are the primary techniques employed by the railroad industry**

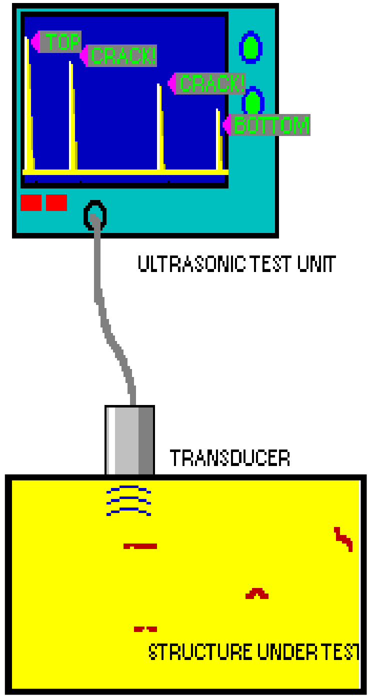
Rail Detector Car

Hand-held UT

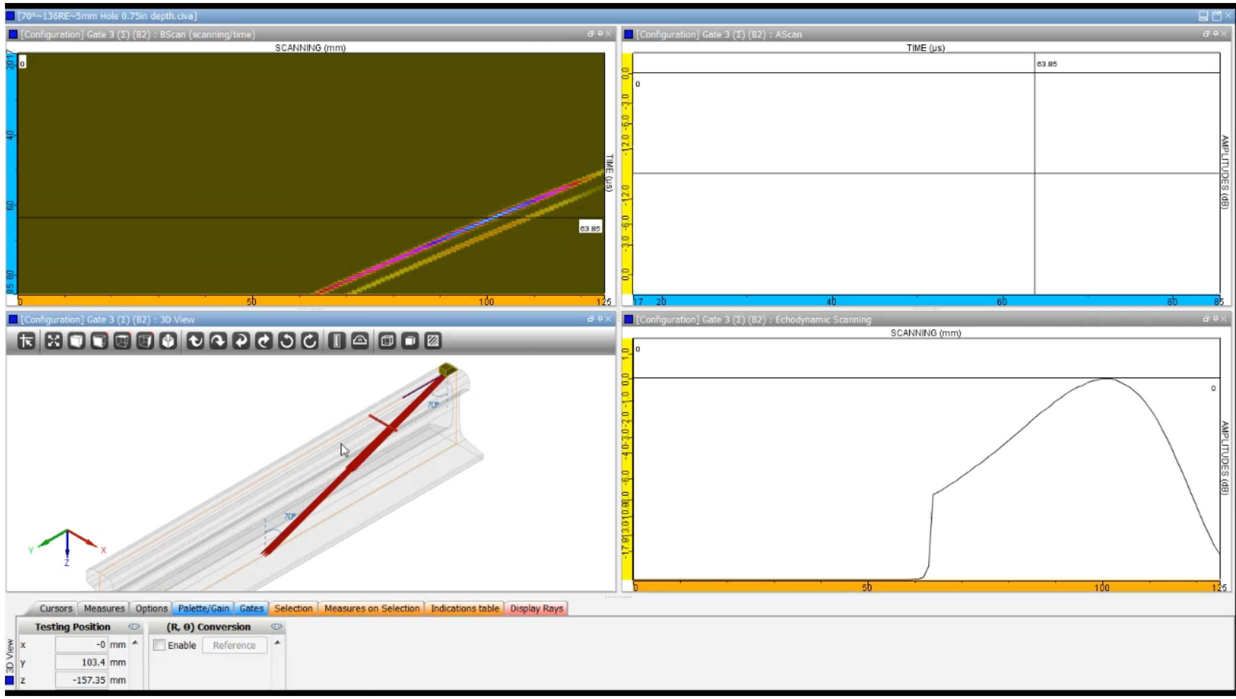
UT Principle

- **UT is based on the principle of ultrasonic wave generation, propagation, and recording/analyzing of reflected wave in materials**

Portable hand-held ultrasonic flaw detector



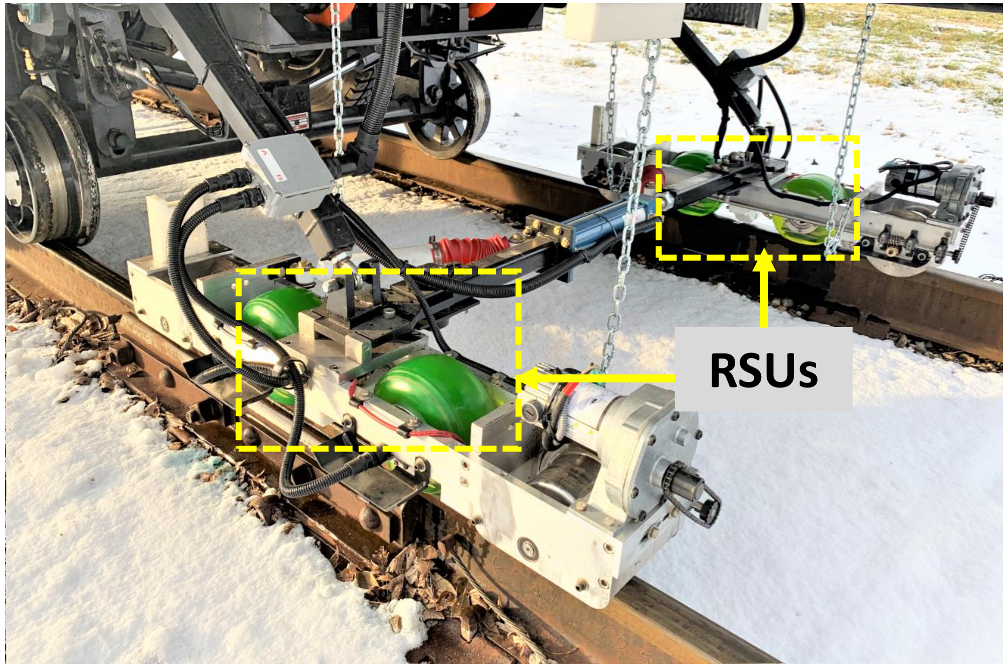
Pulse-echo UT



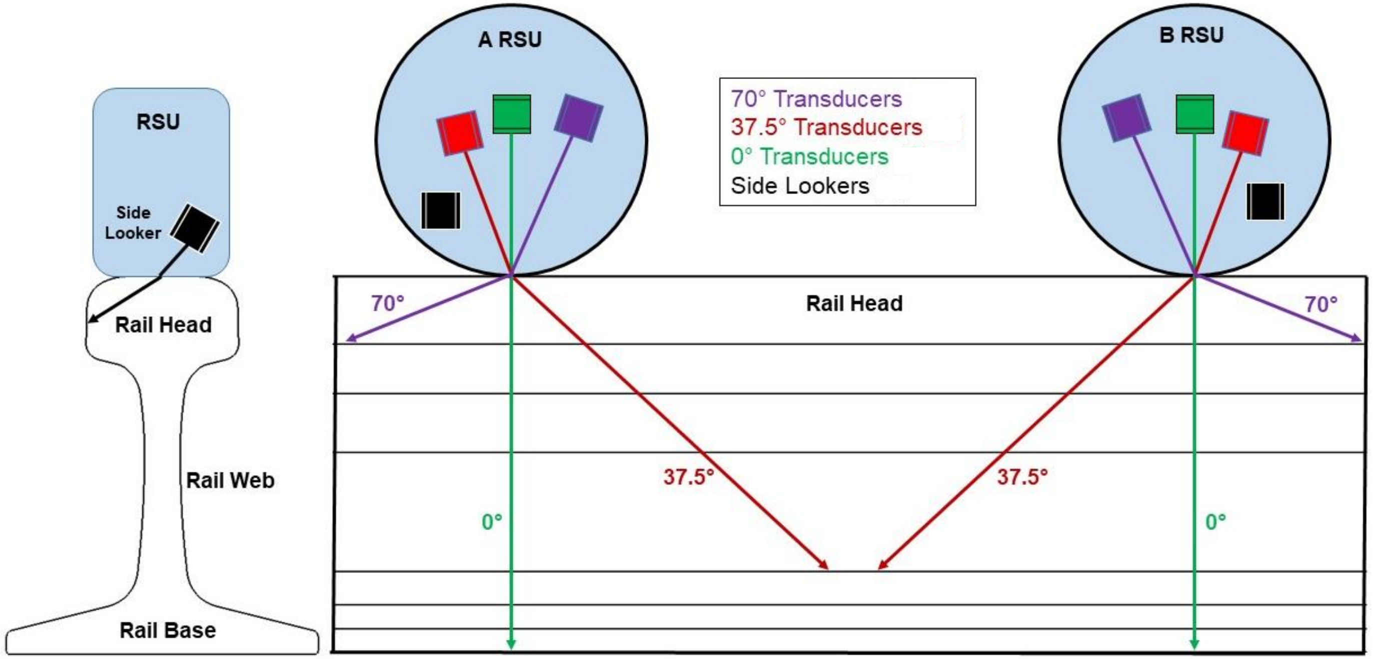
Angle Beam UT

Rail Detector Cars

- **Rail detector cars use fixed angle piezoelectric transducers housed in a liquid filled membrane (tire) called roller search units (RSUs) to generate/emit ultrasonic waves in the rail**



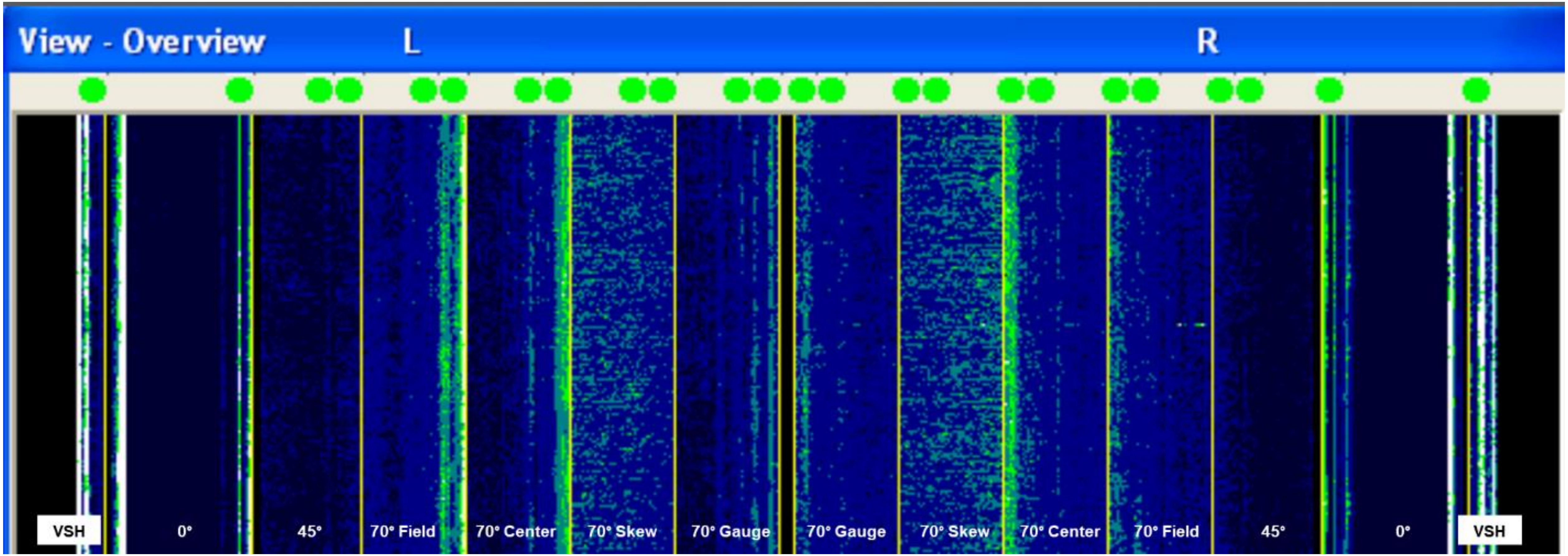
Typical hi-rail carriage



Typical ultrasonic transducers configuration in RSUs for rail testing

Detector Car Rolling B-scan Result

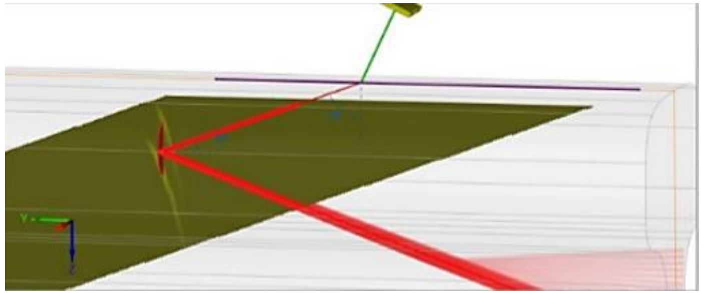
- When a flaw is identified, an alarm is generated to allow the operators to further consider it

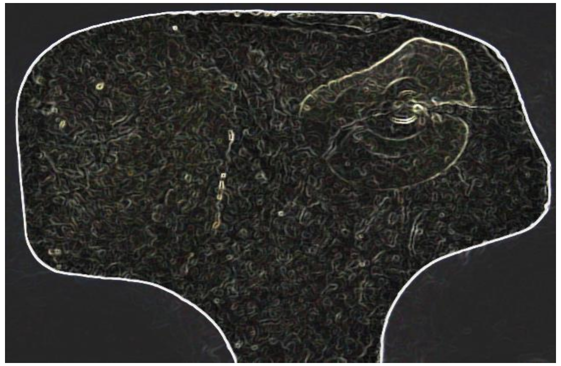


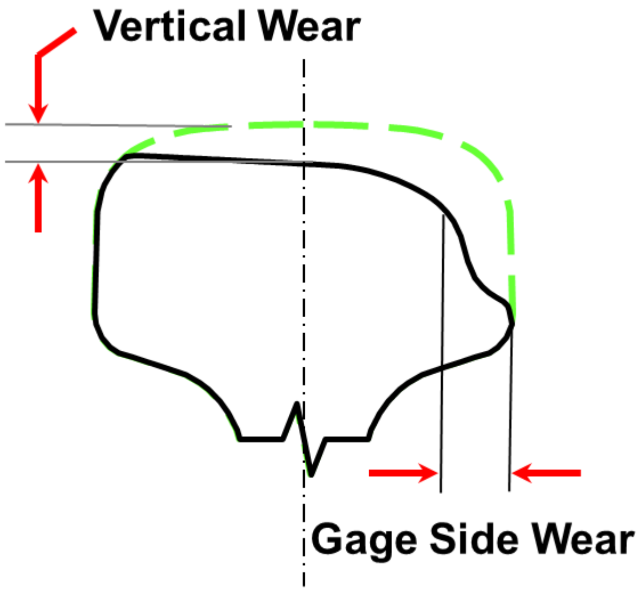
Ultrasonic testing rolling B-scan result

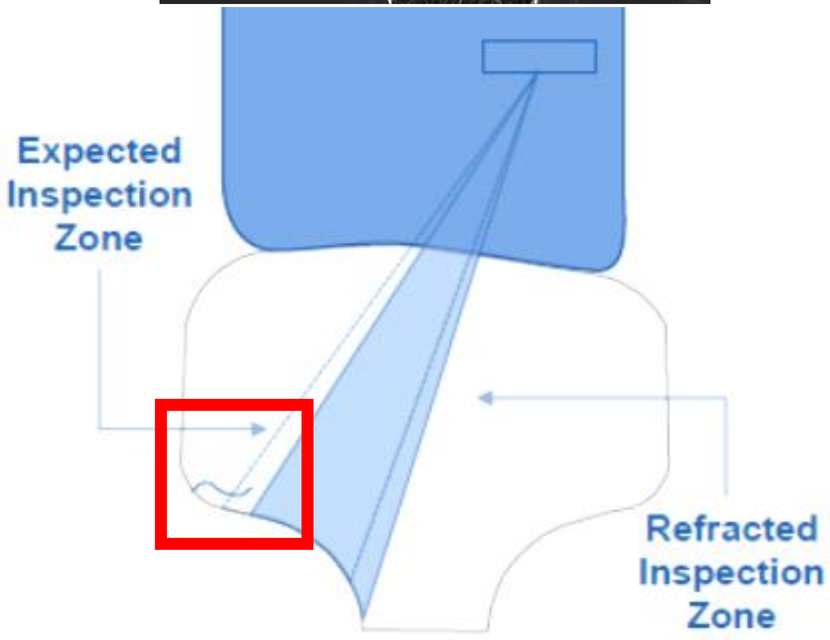
UT Challenges

- **Fixed probe angle approach cannot correct misdirected beam**
  - **Misaligned RSU**
    - Probes and their inspection zone shift with the RSU misalignments
  - **Rail wear**
    - Beam refracted away from the target inspection zone
  - **Defect Orientation**

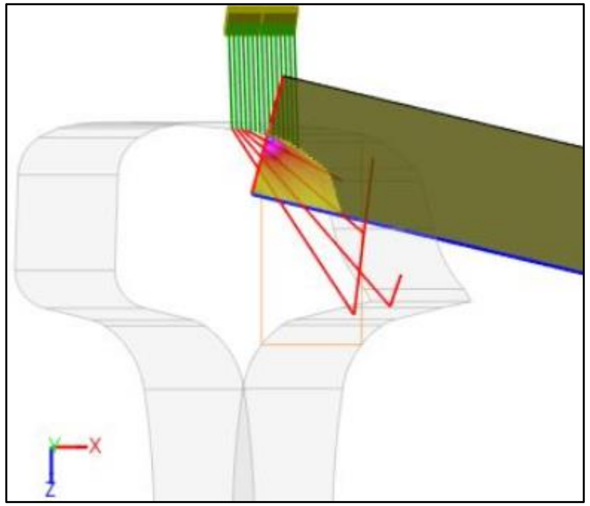








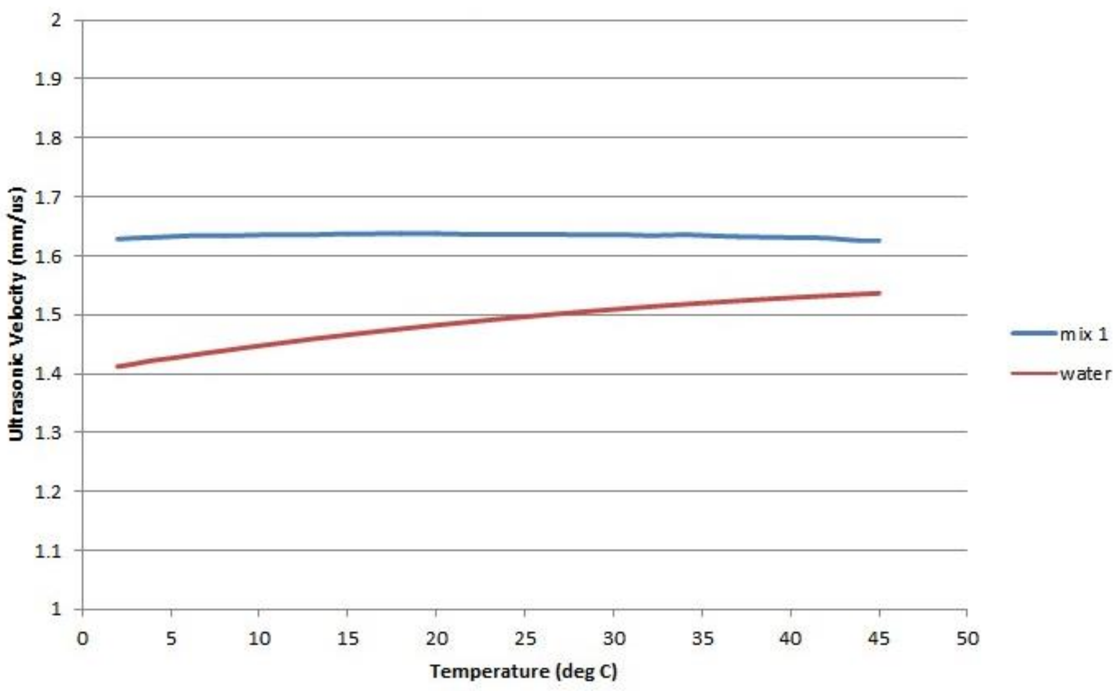
Ultrasonic beam refraction due to worn rail



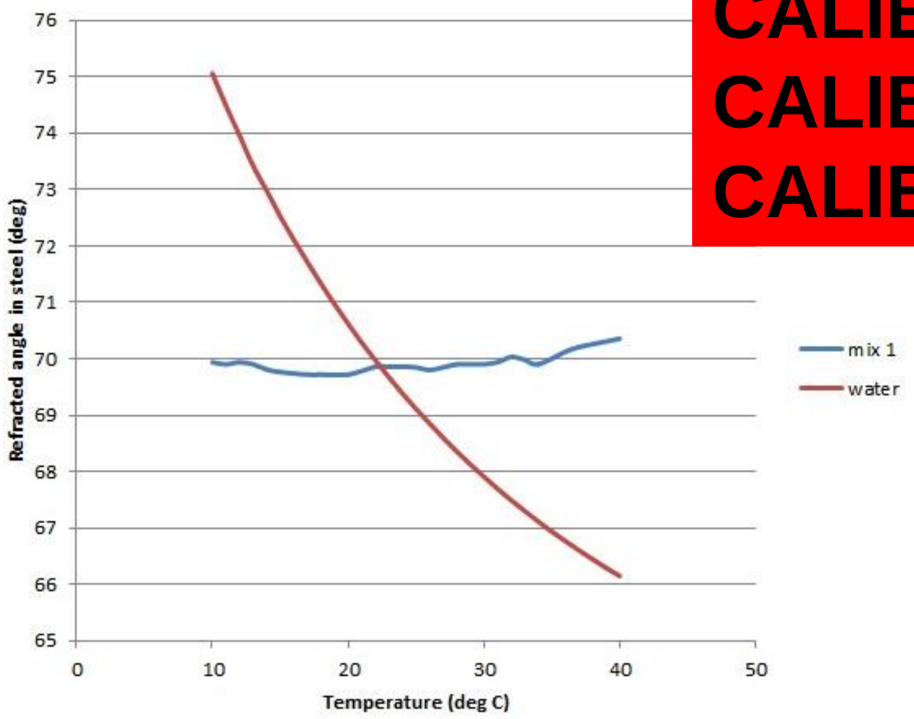
UT Velocity and Beam Refraction

- **When ultrasonic waves travel between two different mediums, its wave propagation is governed by several parameters:**
  - Ultrasonic velocity in medium (temperature & density dependent)
  - Ultrasonic beam refraction (Snell’s Law)

CALIBRATION!
CALIBRATION!
CALIBRATION!



Variation of ultrasonic velocity with temperature



Variation of 70° refracted shear wave with temperature

Rail Flaw Sizing

- **Traditional approach of transverse defect (TD) sizing in the rail head using AREMA provided cross sectional head area (CSHA) may not be valid for severe worn rails due to the head loss, which may cause under-estimating the size of the TD**

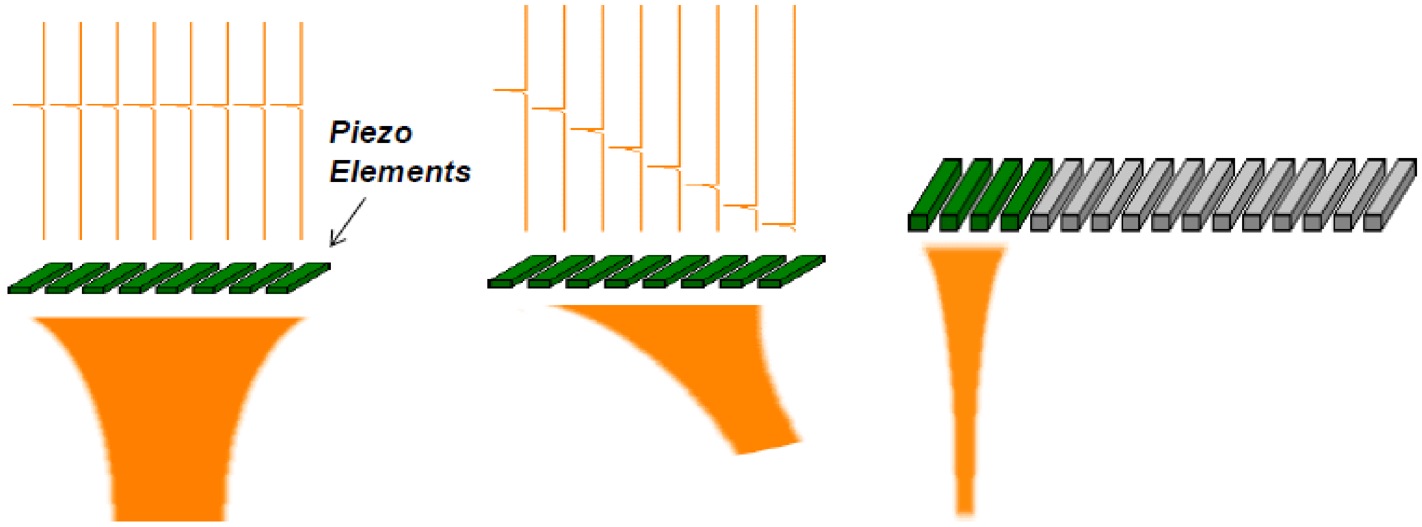
$$TD = \frac{\pi\, l\, w}{4\, A} \times 100\%$$

Rail ID	Physical Measurements						
	Measured Rail Head Area [inch^2]	AREMA Rail Head Area [inch^2]	Square End Mill Diameter [inch]	Defect Orientation Relative to Base [degrees]	TD Sizing - Measured CSHA [%]	TD Sizing - AREMA CSHA [%]	Difference
W2	4.19	4.82	1.25	5°	29.3%	25.5%	3.8%
W3	4.14	4.82	1.25	10°	29.7%	25.5%	4.2%

W: Curve worn (gage face wear)
TD located in Gage side

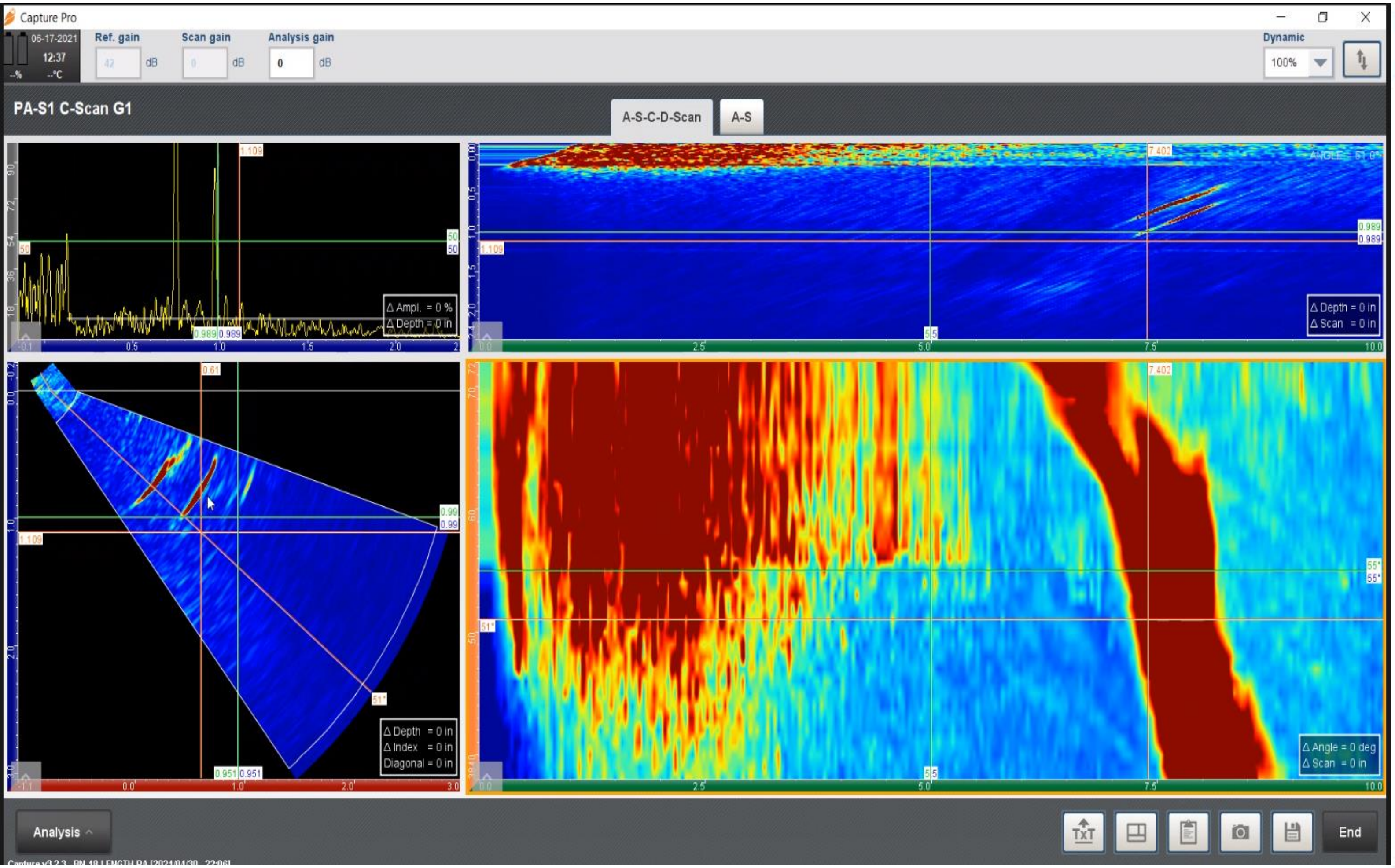
Phased Array Ultrasonic Testing (PAUT)

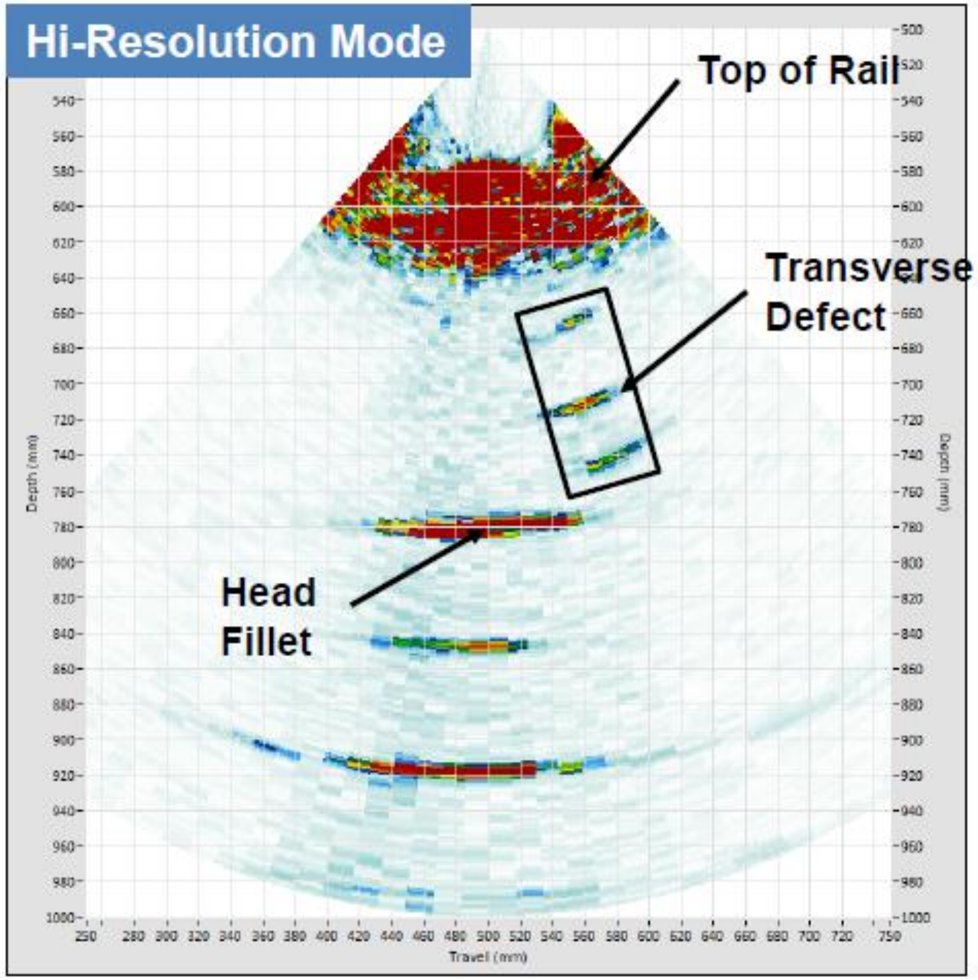
- **PAUT uses multiple ultrasonic crystal elements in the same probe housing**
  - Typically, from 16 to 256 elements
  - By pulsing (firing) the elements in different delay sequences, the beam can be electronically controlled (pulsed separately in a programmed pattern) so it allows for the beam focusing, steering, and electronic scanning



Beam Focusing Beam Steering Electronic Scanning

PAUT Results





32 Elements oriented longitudinally to the rail head

64 Elements oriented transversely to the rail head

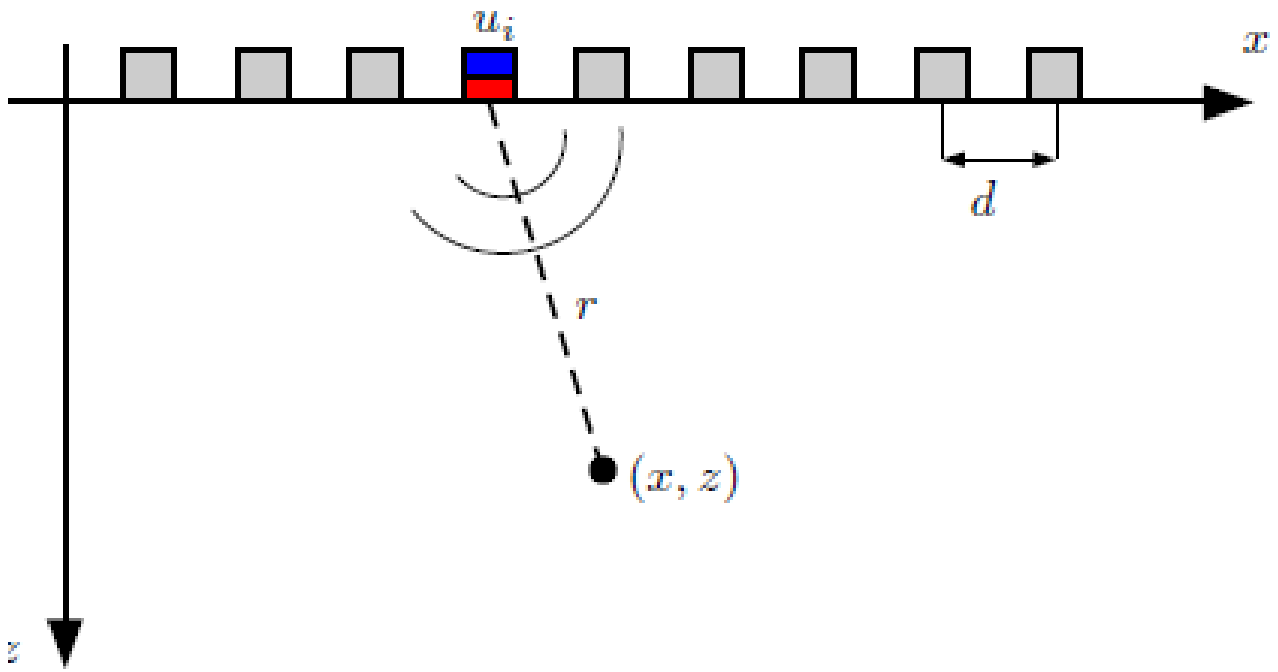
Rail Flaw Sizing Comparisons

Rail ID		Physical Measurements: Defect Orientation [degrees]	Physical Measurements: Actual TD Sizing [%]	Physical Measurements: TD Location	PAUT Measurements: Measured TD [%]	% Difference	Conventional UT Measurements: Measured TD [%]	% Difference
Minimal Head Wear	N1	5°	16.4%	Center	17.5%	1%	2.8%	14%
	N2	10°	16.4%	Center	19.0%	3%	4.0%	12%
Surface Damage	S1	5°	25.7%	Gage	26.7%	1%	8.8%	17%
	S2	10°	27.6%	Gage	27.0%	1%	8.2%	19%
Gage Face Wear	W1	5°	29.3%	Gage	26.5%	3%	13.8%	16%
	W2	10°	29.7%	Gage	30.5%	1%	13.0%	17%

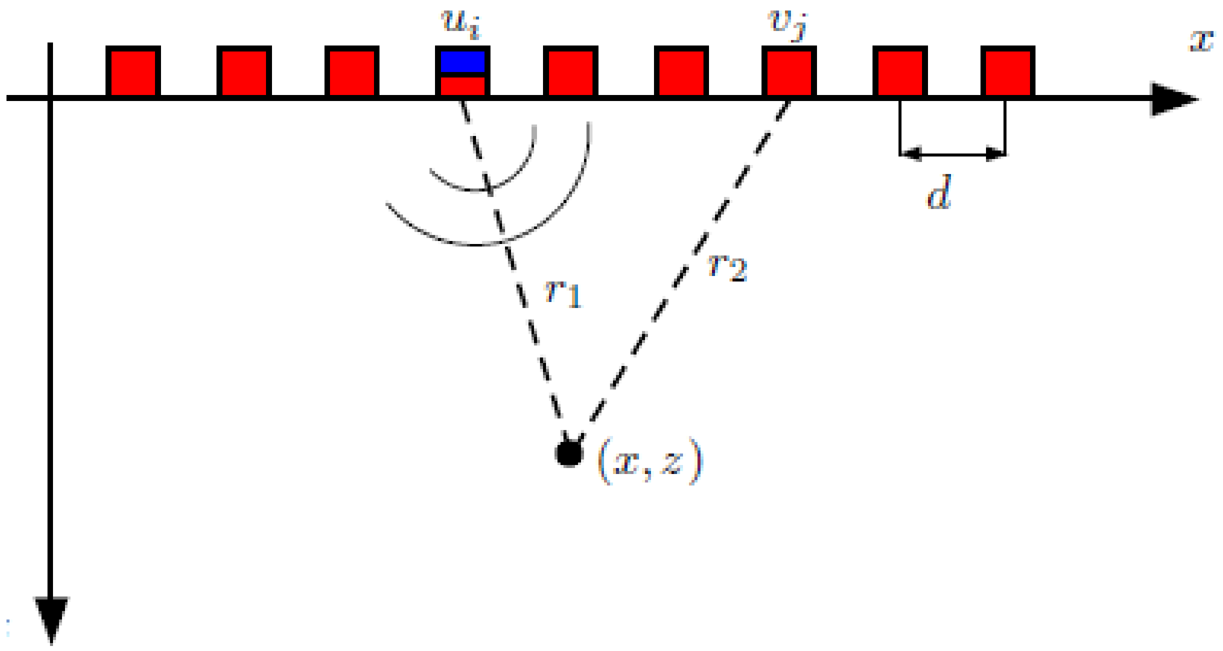
- **Hand-held PAUT sizing provided more accurate than the traditional hand-held UT for RF-LOAD samples for some conditions**

Advanced PAUT Imaging Approaches

- **Synthetic Aperture Focus Technique (SAFT)**
- **Full matrix capture (FMC)/ Total focusing Method (TFM)**



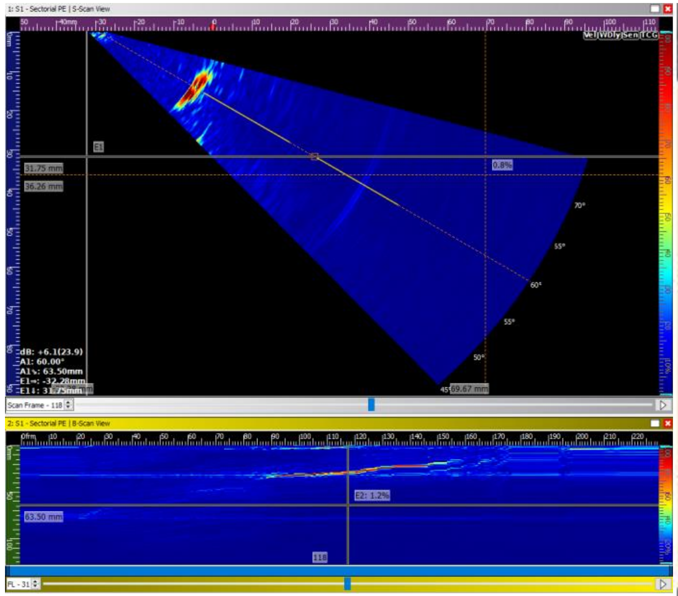
Synthetic Aperture Focus Technique (SAFT)



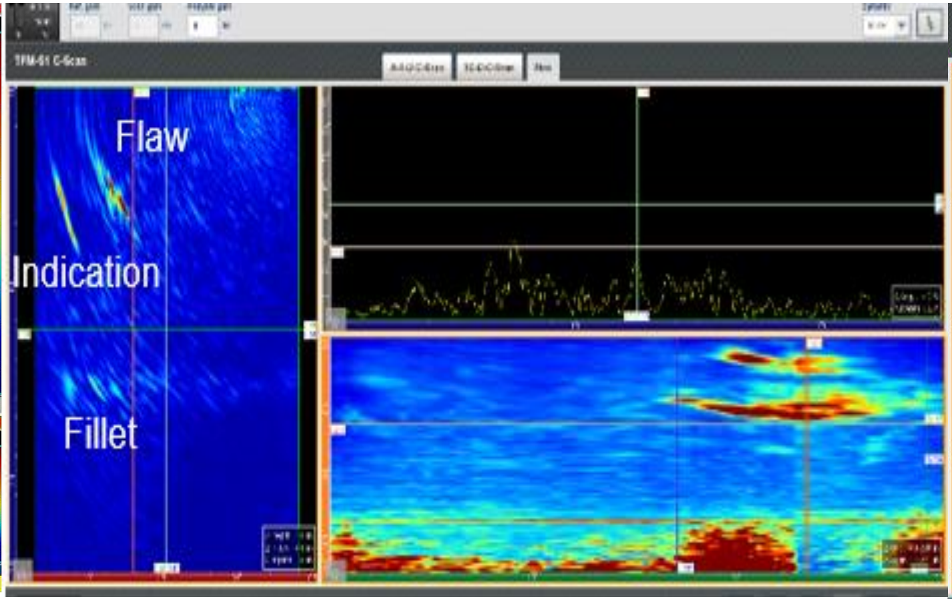
Full matrix capture (FMC)/
Total focusing Method (TFM)

PAUT Results Comparison

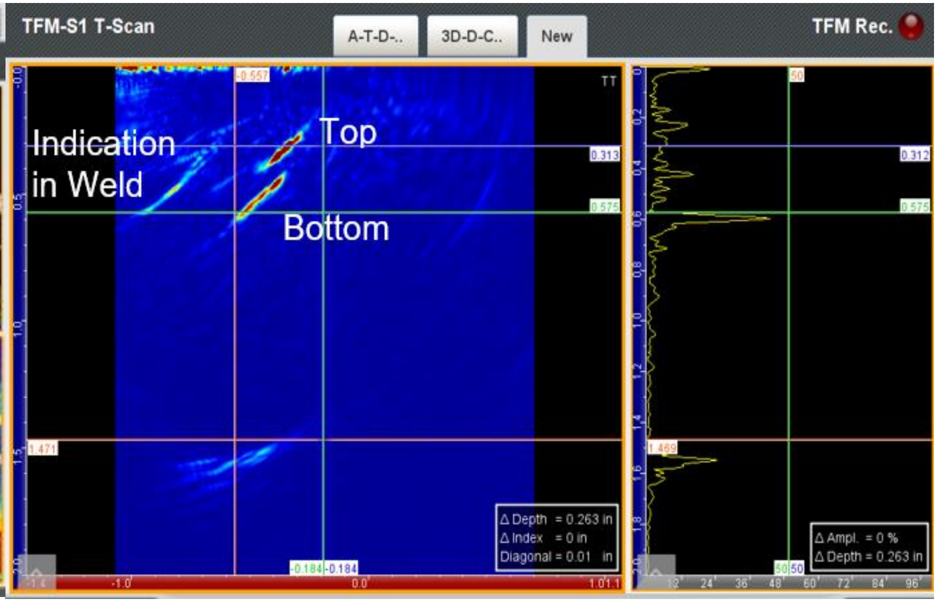
- **Rail sample with TD near a weld**
  - 0.4-inch-wide x 0.6-inch height (approx. 4%)



32-elements 5 MHz Probe



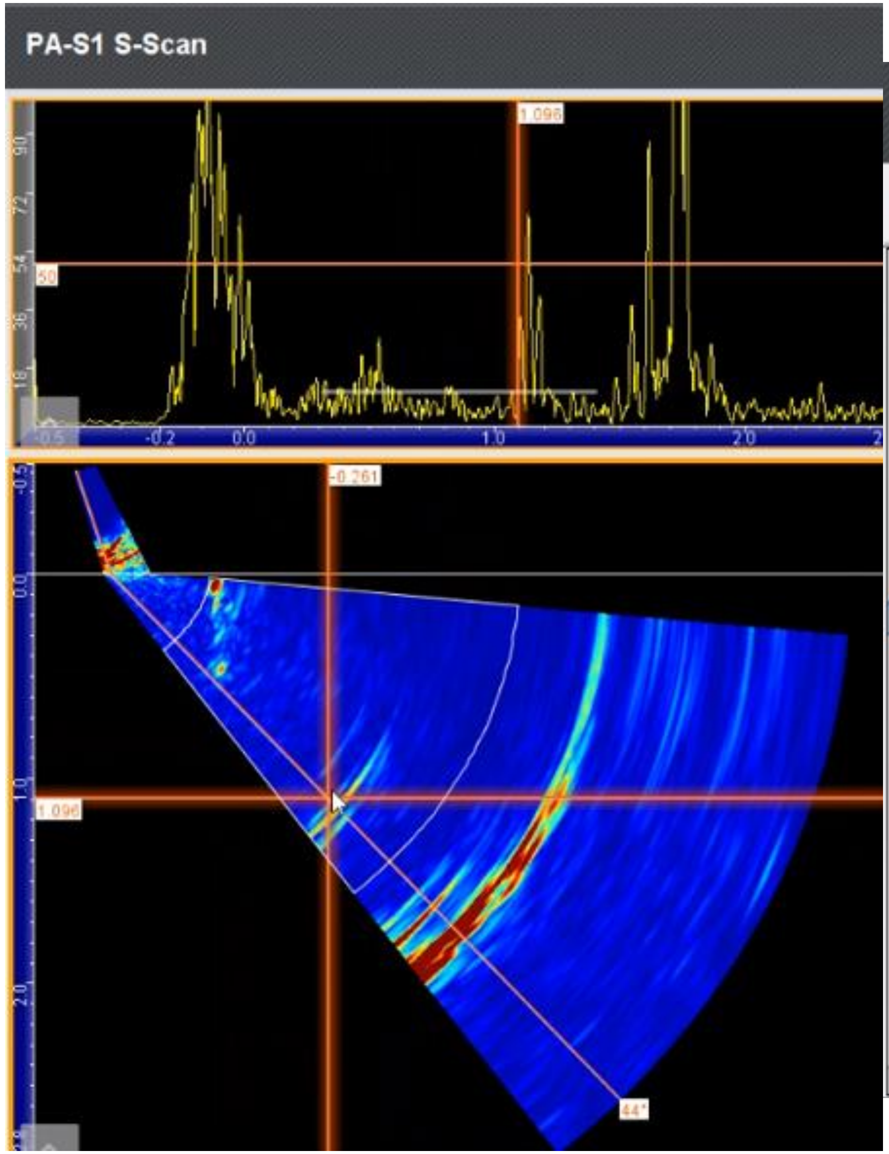
32-element 5 MHz Probe TFM Results

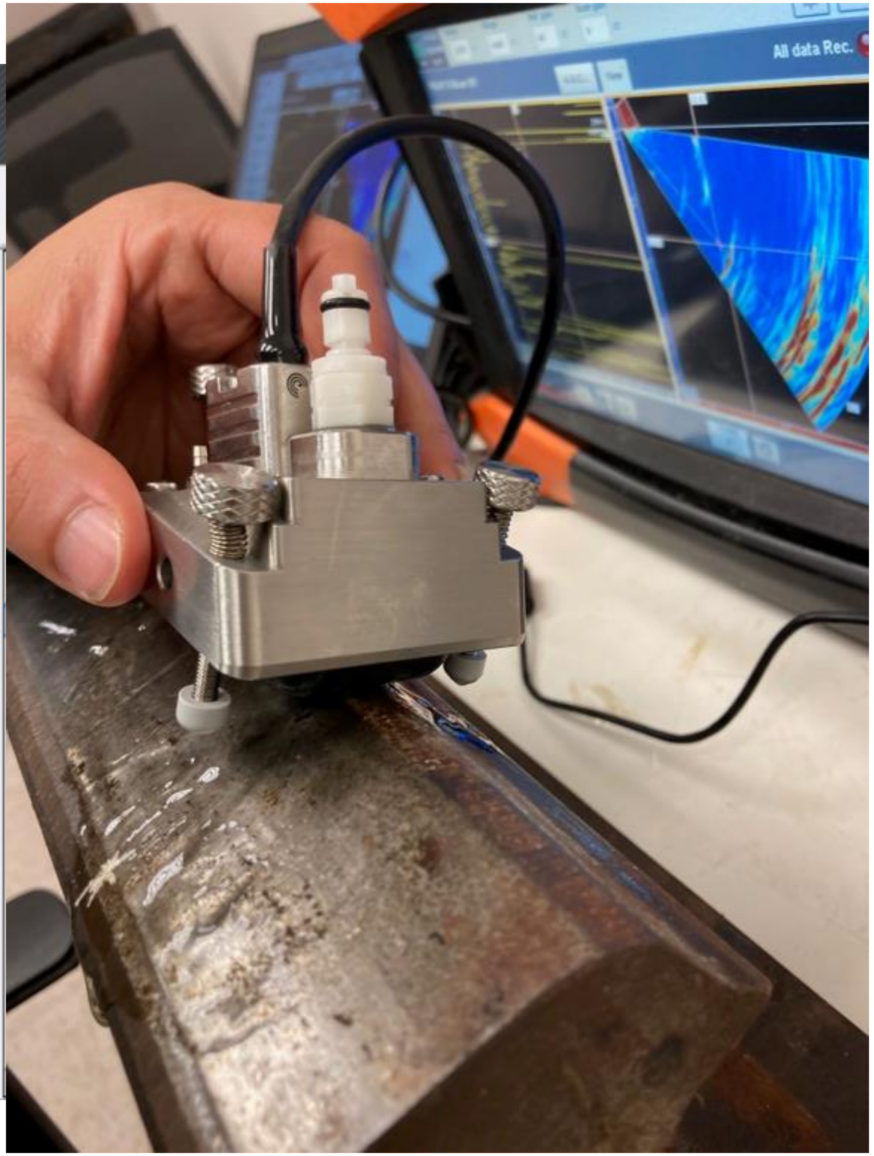


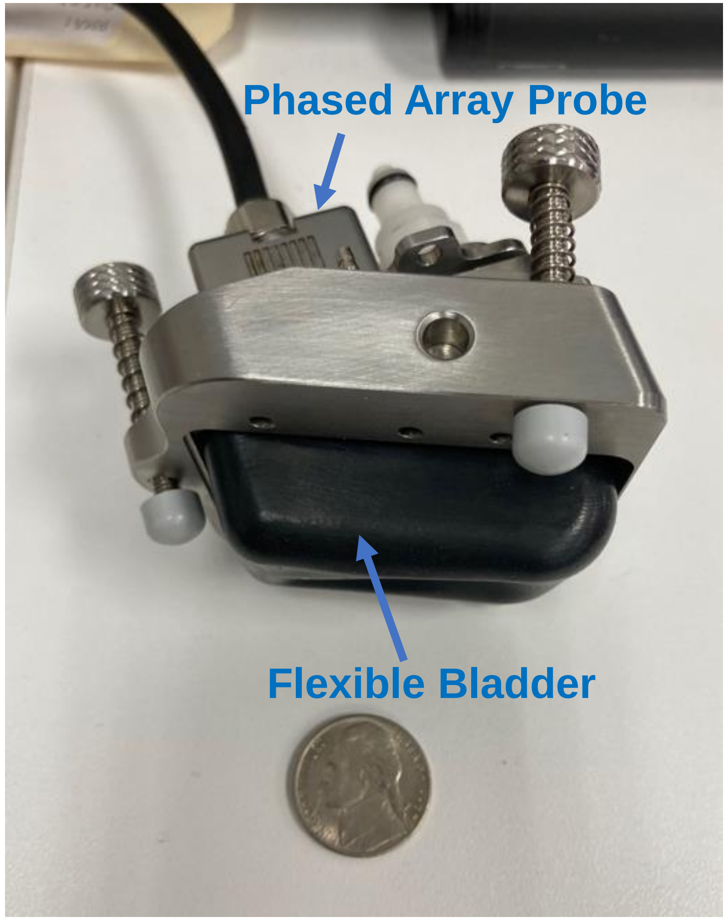
64-element 5 MHz Probe TFM Results

- **TFM/FMC offers additional scan resolution and details for internal rail imaging**
  - Challenges – Rail head wear and rolling contact fatigue (RCF)

Flexible Ultrasonic Probe Array- Ongoing





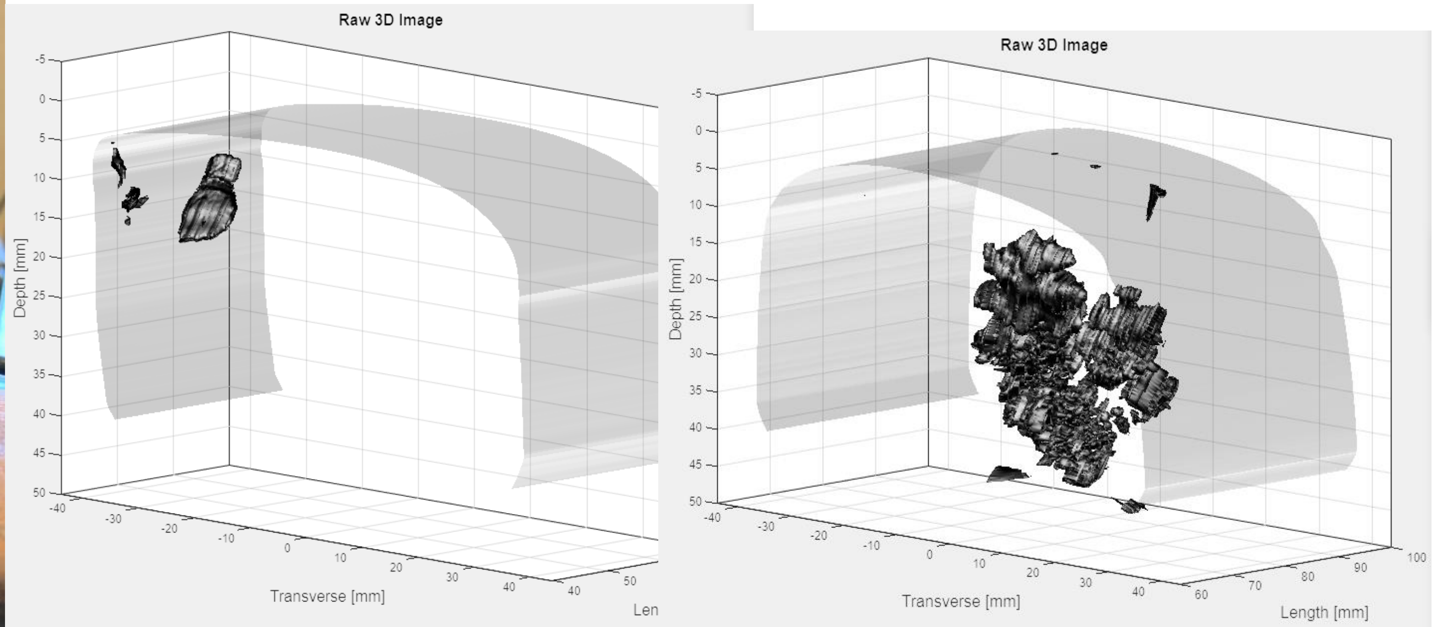


Flexible Ultrasonic Phased Array Probe

UCSD Rail Flaw Imaging

- **GOAL - Develop field deployable robust rail flaw imaging prototype**
  - 3-D image reconstruction from 2-D slices using sparse SAFT with sub-array transmission

UCSD rail flaw imaging setup

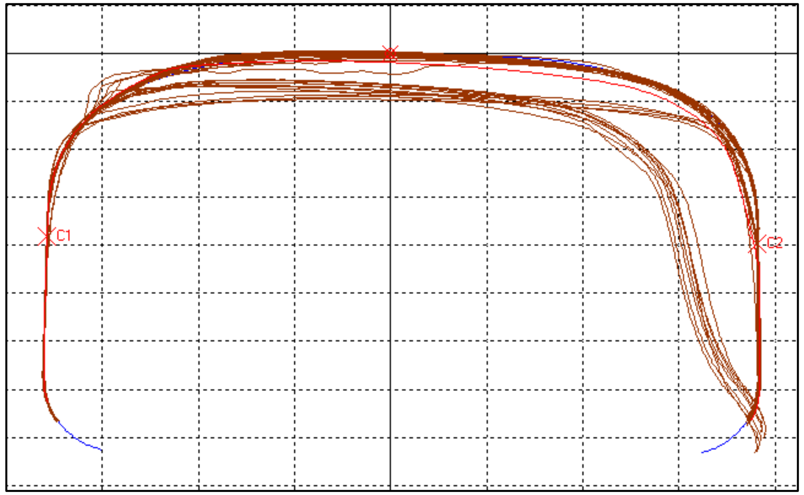


Reconstructed 3-D rail flaw images

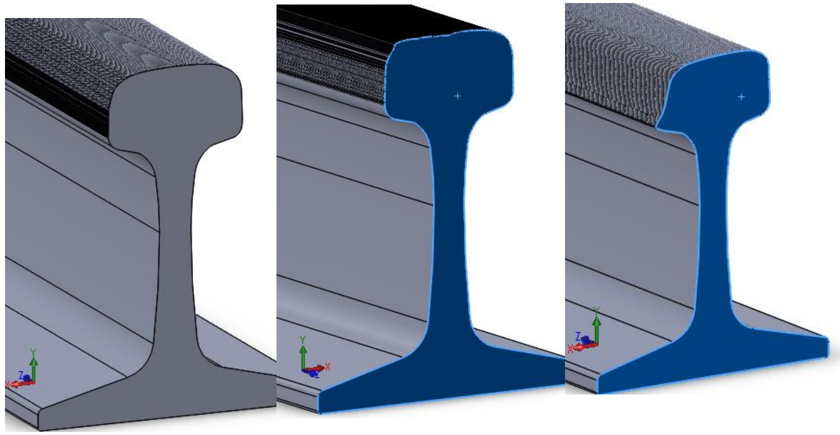
FRA Rail Flaw Library

Current Status

- Artificial Reflectors: **54**
- Service Induced flaws: **62**
  - *TDs, TDs with shells, shells, BHC, VSH, HSH, Inclusions, Wheel burn w/TD, Base Defect*
- No Flaws: **27**
- Broken weld samples (Web/Base Defects): **7**



MiniProf analysis of rail profiles



Solidworks model of RF samples

All rail flaw samples are characterized with higher level of accuracy and standards

Conclusion

- **Rail/Track Inspection is key for assuring Safety & Structural integrity in rails**
  - **GOAL** – 0 TRACK RELATED ACCIDENTS
  - Growing demand for higher axle loads
  - Fatigue defects and RCF are ongoing issues
  - Other challenges

- EQUIPMENT WILL CHANGE TEST METHOD PHYSICS (First Principles) AND INTERACTIONS WILL REMAIN THE SAME!
- If we use the same old tools without innovative methods, we are going to make the same old discoveries
- Doing the same thing over and over while expecting different results is definition of insanity

Example of a Rail Failure

Hand-held Ultrasound Testing

Acknowledgements

- FRA Office of Research and Development for funding this work
- Dr. Robert Wilson, FRA COR
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- North American Class I Railroads
- OEMs and Suppliers of the NDE technology
- Rail Testing Suppliers

DEMONSTRATION

Live UT and PAUT demonstration by TTCI Team

Thank you

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